Geomorphological processes susceptibility assessment using GIS analysis in Ilwis software. Case study: Ialomiţa Upper Valley (Romania)

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Abstract. From a morphological point of view, the Ialomița Upper Valley represents a typical mountain valley. This feature frequently determines the appearance of torrential geomorphological processes (runoff, gulling, and torrent). The goal of this article is to highlight the occurrence of soil erosion using a bivariate analysis in the Ilwis 3.4 software.

Statistical approaches are indirect methods for assessing susceptibility, involving statistical determinations by combining variables that determined the known processes. The weights of evidence modeling for torrential erosion is based on overlapping the erosion map with parameter maps (slope, aspect, geology, land use, soil, etc.),which aims at obtaining the susceptibility map and the final prediction map (success rate map)[1].

Keywords: erosion, susceptibility, maps, statistical analysis, Ialomița Upper Valley.

1. Introduction

The uses of GIS softwares bring many advantages and multiple possibilities of obtaining a complex cartographic material in comparison with the conventional mapping techniques. Through the multiple options to represent the information on a map and the variety of the methods in which the map can be delivered (overlapping several thematic layers, mathematical operations between multiple layers or with digital elevation models, databases connections), maps expressing the cause and the effect are obtained by linking the geology (rock type, structure) with land use, slope with aspect, elevation with geomorphological processes or linking all together (Grecu, 2002, 2009).

Susceptibility to landslides and its mapping are statistically or deterministically evaluated in several studies by international authors (Okimura & Kawatani, 1987; Soeters & van Westen, 1996; Gökceoglu & Aksoy 1996; Tobin & Montzy 1996; Westen et al., 2002; Guzzetti, 2005, Dahal et al., 2008, 2012; Pradhan & Lee, 2010; Regmi et al., 2010; Chauhan et al., 2010) and Romanian authors (Armaş & Damian, 2006; Armaş, 2008[2], 2010; Mihai & Şandric, 2004, Mihai et al., 2008; Chițu & Şandric, 2009; Grecu, 1998, 2002, 2009; Grecu et al., 2010; Şandric, 2010; Dobre, 2011a, 2011b; Dobre et al., 2011).

The bivariate statistical approach is used by many authors to achieve landslide susceptibility map (Bonham-Carter et al., 1990; Agterberg, 1990; Van Westen et al., 2003; Dahal et al., 2008a, b; Armaş, 2010; Regmi et al., 2010). This method has been also applied in order to achieve other types of maps such as a mineral potential map (Emmanuel et al., 2000; Harris et al., 2000; Tangestani and Moore, 2001; Carranza & Hale, 2002), or a map of water accumulation areas (Zahiri et al., 2011). In this study the method is applied for the determination and analysis of torrential erosion processes.

The goal is to establish the susceptibility to erosion using a statistical method, taking into account several morphometric parameters, including morphdynamics and morphogenetic factors like hypsometry, slopes, aspect, geology, land use, soil and geomorphological processes (Grecu et al., 1998).

There are several publications in the international and national literature regarding hazard maps achievement by using statistical analysis. Most of the studies aimed to achieve the landslide

[1] TEODOR, M., ARMAȘ, I., (2012), "Tutorial: Metoda bivariată în evaluarea susceptibilității terenurilor la procese geomorfologice actuale", *Available Online URL:* http://www.geodinamic.ro/upload/fck/Madalina_Teodor-Tutorial_analiza_bivariata.pdf.
[2] ARMAŞ, IULIANA, (2008). „Riscuri naturale (Cultura riscului), Suport de curs h*ttp://www.geodinamic.ro/curs/Sinteze_curs.pdf.*

susceptibility maps. Having these studies as a model, in this paper the method was applied on erosion susceptibility determination in an area belonging to the Romanian Carpathians Mountains (Bucegi Mountains are very representative for the occurrence of geomorphological processes (Velcea, 1961).

The bivariate statistical approach of torrential erosion processes for obtaining the susceptibility erosion map is based on the intersection between erosion map and parameter maps, containing data which leads to determinate the density of complex erosion in the area (van Westen, 2002). A standardization of these values (density) may be obtained by relating them to the overall density (for the entire area studied). Linking can be done using mathematical operations (Exercise L1 - after UNU-ITC School for Disaster Geo-information Management, 2009).

Natural logarithm is used to give negative values when erosion density is lower than normal and provides positive values when erosion density is higher than normal. By gathering the values of the density weight, the final susceptibility map results. It can be analyzed by determining the success rate or the predictive power. (Armaş, 2010; Şandric, 2009).

2. Study area

The studied area is located close to the center of the Bucegi Massif in Carpathians Mountains. It has a horseshoe shape opened to the south. From its center springs the Ialomita River. The Ialomița Upper basin covers an area of 4.5519 square kilometers and has a perimeter of 9.4 kilometers.

Photo 1. **The Ialomița Valley**

The Bucegi Massif is a large synclinal consisting of Mesozoic sedimentary deposits (Jurassic limestone, conglomerates and micaceous sandstones) placed in a transgression process above crystalline schists. It formed at the same time with the entire Carpathians Mountains chain during the Alpine Orogenesis and reaches its maximum altitude in the Omu Peak: 2505 m (Velcea, 1961).

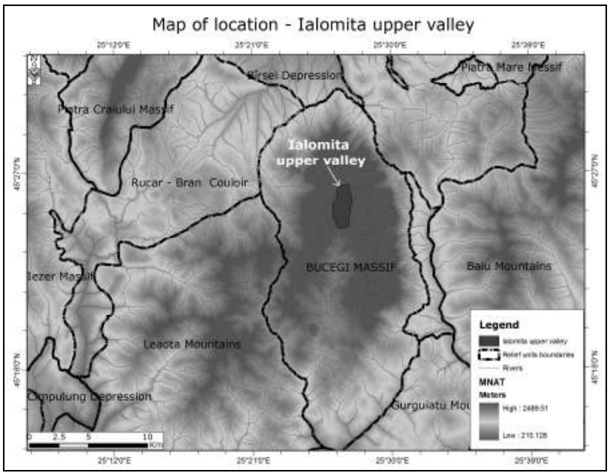


Fig. 1. **Location of the study area**

The horseshoe shape of the Bucegi Massif determines the arrangement and flow direction of the rivers and the torrential bodies (Grecu et al., 2000).

3. Methodology and research stages

To achieve a map of the susceptibility to erosion a statistically-based method was used in the Ilwis 3.4 software (Grecu, 2002). This method uses a limited number of thematic maps (slope, orientation, land use, soil map etc., Grecu et al., 1998) and the map showing one type of erosion (in this study, the torrential erosion map).

Torrential erosion occurs on steep slopes where the water is set quickly in linear drains. The absence or poor vegetation development, heavy rain falls, soft rocks and deposits or anthropogenic activities stimulate the occurrence of geomorphological processes (Ielenicz, 2004).

Working steps:

- *Documentation and field research stages* were started by studying similar analysis from international literature. This stage involved methodology assimilation and bibliographic documentation.
- *Geospatial data collection:* the data held were insufficient; they require updates from mapping, analysis and field observations. Databases are very important because they are a great starting point for a study and they are also an end of it (through the development and updating data).

This study began by collecting, managing and analyzing large volumes of geographic data. After data standardization, the essential elements needed for the analysis were extracted. To carry out the study topographic maps at a 1:25 000 (1982) and a 1:100 000 scale (1982), geological maps at a scale of 1:50 000 (Braşov sheet 1971) and 1:200 000 (Braşov sheet 1969) were used. For the identification and digitalizing of geomorphological processes ortofotoplans 1:5 000 in scale (2005, 2009) and data from numerous field research campaigns were used.

Corine Land Cover vector data (EEA, 2010) were used for the mapping of land use and for the susceptibility determination.

- *Using of GIS techniques* is one of the most important steps, having the purpose to obtain the primary, intermediate and final maps that led to the conclusions sought.

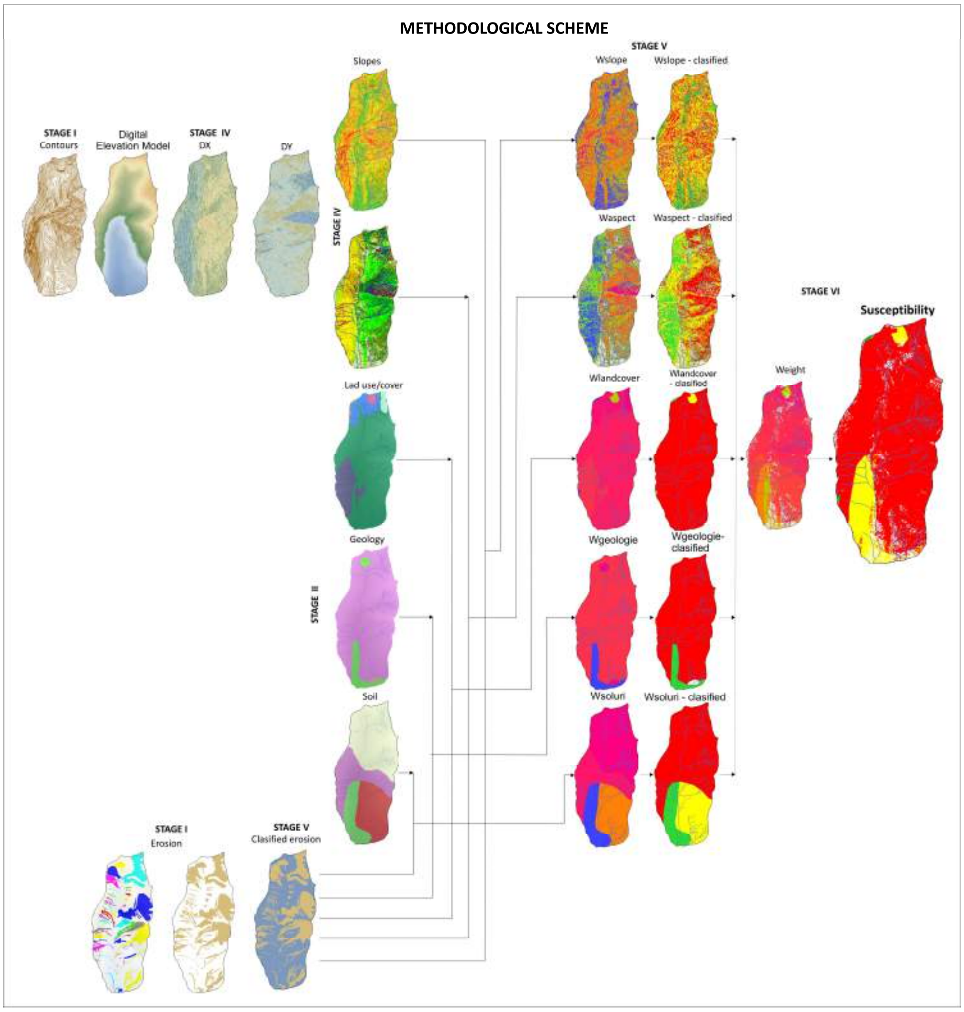


Fig. 2. **Methodological scheme of achieving the susceptibility to erosion**

The graphic material was achieved using specialized GIS software: ILWIS 3.4., ArcGIS 10.1. By the beginning of this stage our purpose was to achieve a *Digital Elevation Model – DEM* (obtained by using elevation contours from the topographic map at a 1:25000 scale (1982) and the ortofotoplan at 1:5000, (2005 and 2009) by applying the *Topo to Raster* interpolation function in ArcGis 10.1), to identify and to digitize the areas affected by torrential erosion. The next step was to import in the Ilwis 3.4 software, all the data needed for the analysis (contours, geology, hydrography, the valley boundaries) and to define the *coordinate system* (Fig. 3). The next step was to realize the parameter maps (hypsometry, slope map, geological map, land use map, soil map, erosion processes map), the torrential erosion susceptibility map and the final susceptibility map.

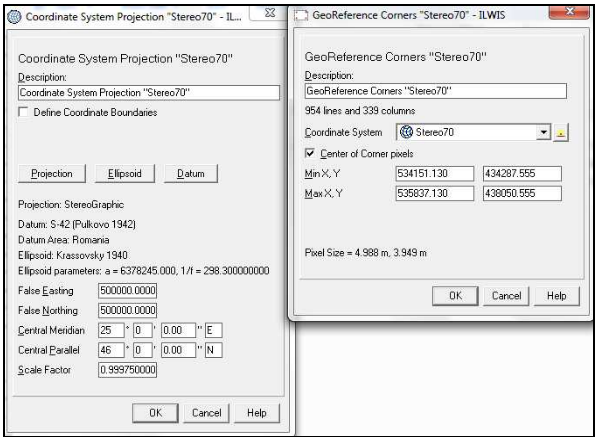


Fig. 3. **Defining the projection and the coordinate system**

Creating parameter maps:

- *Slope map* in Ilwis 3.4 software is achieved by applying on the created DEM, two directional filters: on DX and DY direction. DFDX filter calculates the first derivative in the X direction (dx/dy) per pixel; DFDY filter calculates the first derivative in the Y direction (df/dy) per pixel. (Exercise L1 – after UNU-ITC School for Disaster Geo-information Management, 2009).

The slope map is expressed in degrees and it is achieved by tapping in the main program window the next formula:

„***Slopedeg=RADDEG(ATAN(HYP(DX,DY)/PIXSIZE(DEM)))***”.

The resulting raster map requires reclassification into relevant slope intervals (by creating a new domain, linked with the map).

- *Aspect map:* is achieved by tapping in the main program window the next formula:

„Aspectdeg=RADDEG(ATAN2(DX,DY)+PI”.

The initial result is reclassified into relevant degrees intervals (0-45^0 and 315-361^0 – North, 45-135^0 – East, 315-225^0 – South, 225-315^0 – West).

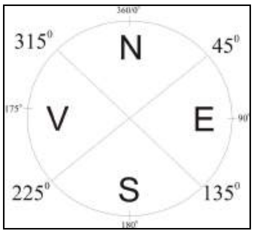


Fig. 4. **Orientation**

Standardization of erosion data into two classes is the next step. “0” is the class represented by areas where the erosion is absent and “1” is the class where torrential erosion occurs. For this standardization the next formulas have to been introduced in the main window of the program:

(***„eroziune=:iff(torentialitate=’eroziune’,1,0”***),

(***„eroziune=:iff(siroire=’eroziune’,1,0)”***).

They will create a raster map which requires removing unknown values. The next formula will be used:

(„eroziunecl:=iff(isundef(eroziune),0,eroziune)”).

This is a base map (Fig. 6) which will be intersected with the parameter maps by comparing the pixels of the same position. These intersections will lead to create new maps and combined tables.

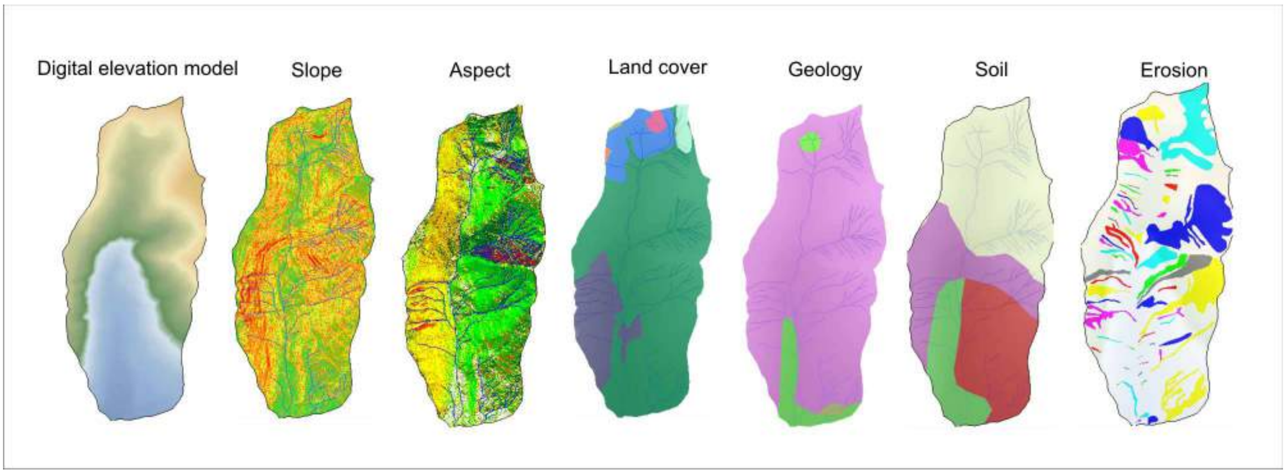


Fig. 5. **Parameter maps**

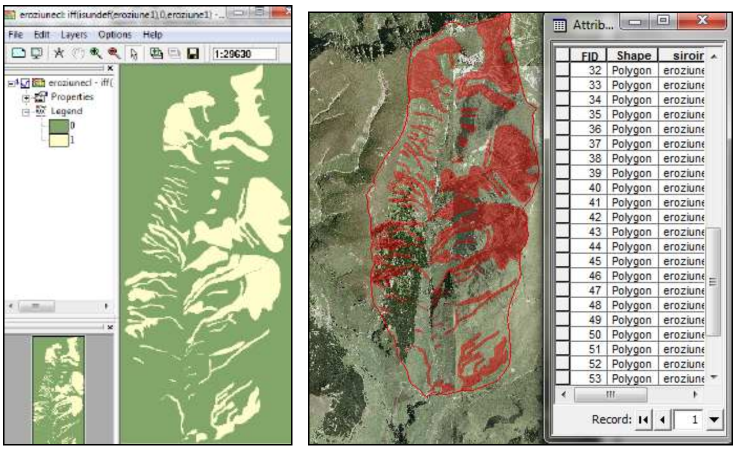


Fig. 6. **Torrential erosion map**

For each parameter the erosion density is calculated. For each parameter interval the active erosion surface is set by applying the formula: ***„AreaAct=iff(eroziunecl=1,area,0”***, then it is required to calculate the total area occupied by each interval (using *Aggregation* and *Sum* functions). The next step is to calculate the area of active erosion of each interval of the parameters (using *Aggregation* function, selecting to sum the values of the column that contains the area and grouping results by parameter range) and to calculate the total area of the map and the total area affected by erosion in order to determine the erosion density on each slope class (or aspect, geology, land use, soil classes). This will be done by applying the following function:

„Densclas=Areaslopeact/Areslopetot”.

Also the density of the erosion on the entire map is calculated by applying the formula:

„Densmap = Areamapact/ Areamaptot”.

In order to avoid "0" density appearance, the next function will be applied:

„Dclas:=iff(Densclas=00.0001,Densclas)”.

For each parameter will result a table containing quantitative information.

	slopecl3	eroziunecl	NPix	Area	AreaAct	Areaslopetot	Areaslopeact	Areamaptot	Areamapact	Densclas	Densmap
0-10 * 0	0-10	0	597372	597372	0	771685	174313	4534286	1563373	0.2259	0.3448
0-10 * 1	0-10	1	174313	174313	174313	771685	174313	4534286	1563373	0.2259	0.3448
10-20 * 0	10-20	0	235733	235733	0	341726	105993	4534286	1563373	0.3102	0.3448
10-20 * 1	10-20	1	105993	105993	105993	341726	105993	4534286	1563373	0.3102	0.3448
20-30 * 0	20-30	0	550501	550501	0	863332	312831	4534286	1563373	0.3624	0.3448
20-30 * 1	20-30	1	312831	312831	312831	863332	312831	4534286	1563373	0.3624	0.3448
30-40 * 0	30-40	0	737229	737229	0	1195009	457780	4534286	1563373	0.3831	0.3448
30-40 * 1	30-40	1	457780	457780	457780	1195009	457780	4534286	1563373	0.3831	0.3448
40-50 * 0	40-50	0	660875	660875	0	990622	329747	4534286	1563373	0.3329	0.3448
40-50 * 1	40-50	1	329747	329747	329747	990622	329747	4534286	1563373	0.3329	0.3448
50-60 * 0	50-60	0	173456	173456	0	336044	162588	4534286	1563373	0.4838	0.3448
50-60 * 1	50-60	1	162588	162588	162588	336044	162588	4534286	1563373	0.4838	0.3448
60-70 * 0	60-70	0	15584	15584	0	35332	19748	4534286	1563373	0.5589	0.3448
60-70 * 1	60-70	1	19748	19748	19748	35332	19748	4534286	1563373	0.5589	0.3448
70-80 * 0	70-80	0	163	163	0	536	373	4534286	1563373	0.6959	0.3448
70-80 * 1	70-80	1	373	373	373	536	373	4534286	1563373	0.6959	0.3448

Fig. 7. **Table containing quantitative information**

	Areaslopetot	AreaSlopeAct	Densclas	Dclass	Weight
0-10	771685	174313	0.2259	0.2259	-0.4229
10-20	341726	105993	0.3102	0.3102	-0.1057
20-30	863332	312831	0.3624	0.3624	0.0498
30-40	1195009	457780	0.3831	0.3831	0.1053
40-50	990622	329747	0.3329	0.3329	-0.0351
50-60	336044	162588	0.4838	0.4838	0.3387
60-70	35332	19748	0.5589	0.5589	0.4830
70-80	536	373	0.6959	0.6959	0.7022

Fig. 8. **Simplified table** (for each parameter)

These tables will be simplified for achieving susceptibility maps (Fig. 8).

Using the erosion density depending on the parameter's interval one can calculate the weight by extracting the natural logarithm taking into account that the density of erosion in the map is equal to 0.3448 (areamapact: 1563371/Areamaptot: 4535286):

„Weight:=ln(Dclas/0.3448)”.

To achieve the susceptibility maps we will use the „Weight" column (Fig. 8) which will be classified into three main classes of susceptibility (by analyzing the results and creating a new domain. We will choose three intervals according to the data previously obtained. The map called "Wslope_cl" results[3].

[3] RiskCity exercise 3L1, „Hayard Landslides statistical method". http://eusoils.jrc.ec.europa.eu/esdb_archive/eusoils_docs/other/eur22904en.pdf (Armaş Iuliana, Gheorghe Diana, (2009), Exercitiul L1. Evaluarea susceptibilității la alunecare prin metode statistice (exercițiu preluat după UNU-ITC School for Disaster Geo-information Management, 2009).

The last step is to achieve the torrential erosion susceptibility map. In order to achieve this map we will gather all other previous data by applying the formula:

„Weight:=WAspect_cl+Wgeologica+WLand_cl+W Slope_cl+WSoluri_cl”.

4. Results and discussion

Slope map (Fig. 9a) indicates the presence of higher slopes (60-80^0) on the Eastern side of the valley. By analyzing the graph and the associated table the predominance of 30-40 degrees slopes (on 5.84 km^2 – representing 26%) is observed, followed by sopes in the 40-50 degrees interval (4,84 km^2 – 22%). Lower values are recorded along the main riverbed and on the side valleys. *The aspect map* (Fig. 9b) shows the predominance of East oriented slopes (4.36 km^2 – 14%), West oriented slopes (4 km^2 + 13%) and South-West oriented slopes (3.6 km^2). *The land cover map* (Fig. 9c) shows the predominance of natural pastures – 54%, subalpine vegetation in the North-West of the map and rock areas in the North. The *geological map* (Fig. 9d) highlights the presence of conglomerates and sandstones 66%, deposits - 5%. The *soil map* (Fig. 9e) shows the predominant presence of acid brown criptospodic soils and feriiluvial podzols in the North, podzols, litosoils and rocks in the center of the map's area.

The medium susceptibility is indicated by intersecting the torrential erosion map with slopes map. The high susceptibility appears on 20-50 degrees slopes. The potential of torrential erosion is influenced by slope inclination.

After intersecting the erosion map with aspect map (Fig. 9) it is observed that the medium susceptibility appears on East and Southeast oriented slopes and high susceptibility on West oriented slopes. South and South-East slopes receive the most powerful solar radiation thus they are the warmest and driest slopes, being the most favorable for occurrence and development of geomorphological processes. Greater significance has the heating in the winter because of fast snow melt and a longer period for processes to appear. West and South-West oriented slopes are half warm and half dry and present mostly a higher susceptibility in the analyzed area. Half wet and half cold slopes are represented by East and North-West slopes which have a low potential for erosion process. The less favorable slopes are the cold and wet ones. They are protected by snow cover over a long period of the year because of the North and North-East orientation.

Susceptibility to erosion map intersected with the land use map indicates a higher susceptibility on natural pasture and on 70% of the entire map. Susceptibility map intersected with geological map indicates the appearance of high values corresponding to limestones and sandstones (90% of the total surface). Low susceptibility appears on 7 % in the south of the area, because of the gravels, sands and glacial deposits. Susceptibility map intersected with the soil map indicates the occurrence of high values of susceptibility in the North on the map corresponding to high altitudes, where brown acid criptosodic soils and podzol soils have developed. Low susceptibility corresponds to areas situated on the riverbed.

According to the final results (Figs. 11 and 12) the high susceptibility to erosion is registered on 87% from total analyzed area. Moderate susceptibility is registered on 8.67% corresponding to the 10-40 degree East orientated slopes represented by natural pastures developed on conglomerates and brown acid soils. Low susceptibility is registered in the North-East on 0.14% of the map corresponding to lower Eastern slopes with sparse vegetation on conglomerates, sandstones and brown acid and ciptospodic soils (Figs. 9 and 11).

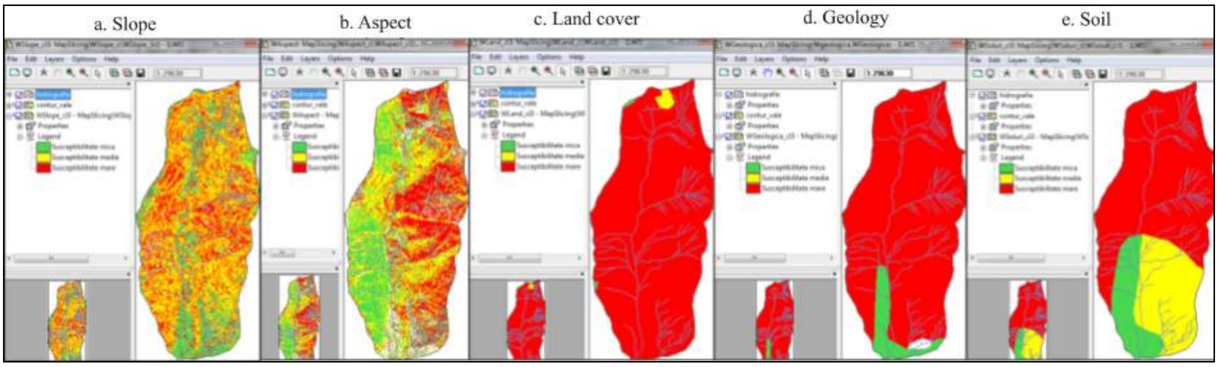


Fig. 9. **Map susceptibility classified into three classes based on the initial parameters**

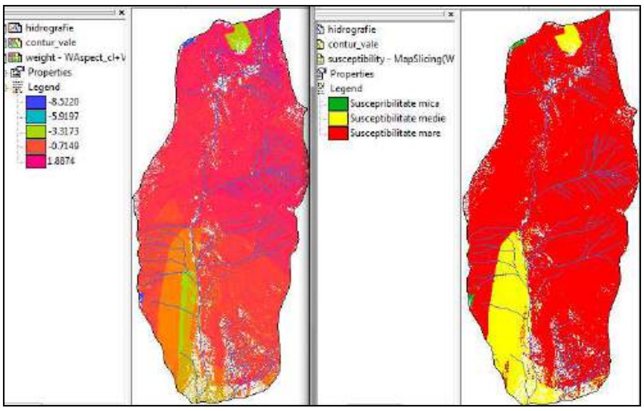


Fig. 10. **Torrential erosion susceptibility map**

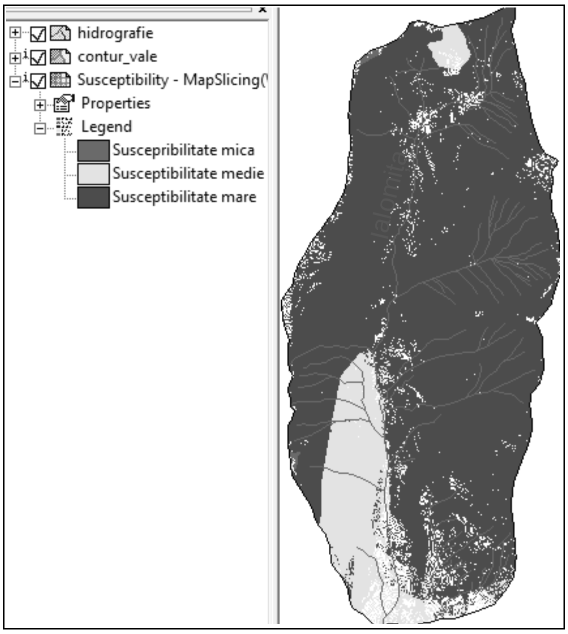
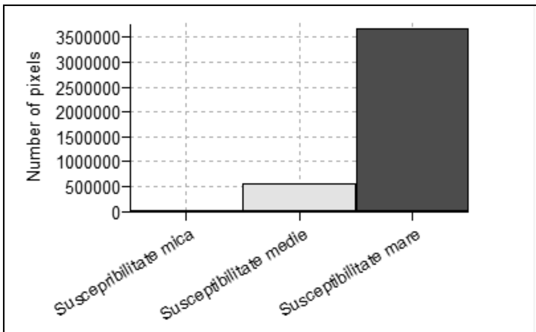


Fig. 11. **Torrential erosion susceptibility map**



	npix	npixpct	pctnotund	Area
Suscepribilitate mica	9182	0.14	0.22	9182
Susceptibilitate medie	551222	8.68	12.99	551222
Susceptibilitate mare	3684262	58.04	86.80	3684262
Min	9182	0.14	0.22	9182
Max	3684262	58.04	86.80	3684262
Avg	1414889	22.29	33.34	1414889
StD	1983934	31.26	46.74	1983934
Sum	4244666	66.86	100.01	4244666

Pred=Susceptibilitate mare (3684262)
Number of Undef pixels = 2103515 (33.14%)

Fig. 12. **The graph and statistical data**

Dependent Table "WEroziune" - TableCross(Weight.mpr,eroziunecl.mpr,IgnoreUndefs) - ILWIS

File Edit Columns Records View Help

	Weight	eroziunecl	NPix	Area	npixact	Npcumactive	totaleroz	totalarea	percentage	Percenteroz	Npixcumul	reverse	percentmap
-8.5220 * 0	-8.5220	0	398	398	0	0	1504187	4244666	0.00	100.00	398	4244268	99.99
-8.4239 * 0	-8.4239	0	120	120	0	0	1504187	4244666	0.00	100.00	518	4244148	99.99
-8.3228 * 0	-8.3228	0	275	275	0	0	1504187	4244666	0.00	100.00	793	4243873	99.98
-8.2939 * 0	-8.2939	0	184	184	0	0	1504187	4244666	0.00	100.00	977	4243689	99.98
-8.2807 * 0	-8.2807	0	18	18	0	0	1504187	4244666	0.00	100.00	995	4243671	99.98
-8.2384 * 0	-8.2384	0	296	296	0	0	1504187	4244666	0.00	100.00	1291	4243375	99.97
-8.2247 * 0	-8.2247	0	822	822	0	0	1504187	4244666	0.00	100.00	2113	4242553	99.95
-8.2048 * 0	-8.2048	0	106	106	0	0	1504187	4244666	0.00	100.00	2219	4242447	99.95
-8.1958 * 0	-8.1958	0	472	472	0	0	1504187	4244666	0.00	100.00	2691	4241975	99.94
-8.1403 * 0	-8.1403	0	930	930	0	0	1504187	4244666	0.00	100.00	3621	4241045	99.91
-8.0947 * 0	-8.0947	0	237	237	0	0	1504187	4244666	0.00	100.00	3858	4240808	99.91
-8.0605 * 0	-8.0605	0	2	2	0	0	1504187	4244666	0.00	100.00	3860	4240806	99.91
-8.0131 * 0	-8.0131	0	1190	1190	0	0	1504187	4244666	0.00	100.00	5050	4239616	99.88
-8.0061 * 0	-8.0061	0	237	237	0	0	1504187	4244666	0.00	100.00	5287	4239379	99.88
-8.0056 * 0	-8.0056	0	132	132	0	0	1504187	4244666	0.00	100.00	5419	4239247	99.87
-8.0050 * 0	-8.0050	0	3	3	0	0	1504187	4244666	0.00	100.00	5422	4239244	99.87
-7.9624 * 0	-7.9624	0	790	790	0	0	1504187	4244666	0.00	100.00	6212	4238454	99.85
-7.9512 * 0	-7.9512	0	14	14	0	0	1504187	4244666	0.00	100.00	6226	4238440	99.85
-7.9194 * 0	-7.9194	0	415	415	0	0	1504187	4244666	0.00	100.00	6641	4238025	99.84
-7.9150 * 0	-7.9150	0	325	325	0	0	1504187	4244666	0.00	100.00	6966	4237700	99.84
-7.9075 * 0	-7.9075	0	283	283	0	0	1504187	4244666	0.00	100.00	7249	4237417	99.83
-7.9069 * 0	-7.9069	0	40	40	0	0	1504187	4244666	0.00	100.00	7289	4237377	99.83
-7.8957 * 0	-7.8957	0	47	47	0	0	1504187	4244666	0.00	100.00	7336	4237330	99.83
-7.8775 * 0	-7.8775	0	1	1	0	0	1504187	4244666	0.00	100.00	7337	4237329	99.83
-7.8727 * 0	-7.8727	0	293	293	0	0	1504187	4244666	0.00	100.00	7630	4237036	99.82
-7.8220 * 0	-7.8220	0	282	282	0	0	1504187	4244666	0.00	100.00	7912	4236754	99.81

Fig. 13. **Table containing information from the final susceptibility map**

High susceptibility is determined by physical and geographical favorable conditions for the occurrence of erosion processes. Steep slopes (specific to mountain area) determine rainfalls or snowmelt water to concentrate along gutters..

The ***predictive power*** analyses whether this method is useful by calculating the success rate by ordering decreasingly the pixels of the final susceptibility map using the frequency from the histogram (Fig. 15). This is overlapped with the actual erosion map and the common frequency is calculated. The success rate indicates the percentage from the total number of pixels corresponding to actual erosion, which occurs in the areas with the highest values of final susceptibility to erosion.

To calculate the success rate we applied a script (with several statistical operations shown in the Figure below) that will combine the Weight columns from tables that contain erosion. (Exercise L1 – after UNU-ITC School for Disaster Geo-information Management, 2009).

The final step is the creation of the success rate graph. It can be created by selecting on the OX axis the percentage from the total map area and on OY axis the percentage from the total area with observed erosion.

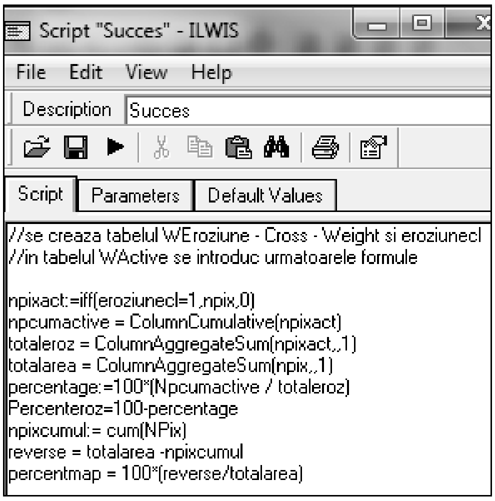


Fig. 14. **Script applied to determine the success rate**

Analyzing the final graph (Fig. 15) it is noted that 80% of the total erosion is predicted over 60% of the total area, corresponding to the highest values of susceptibility.

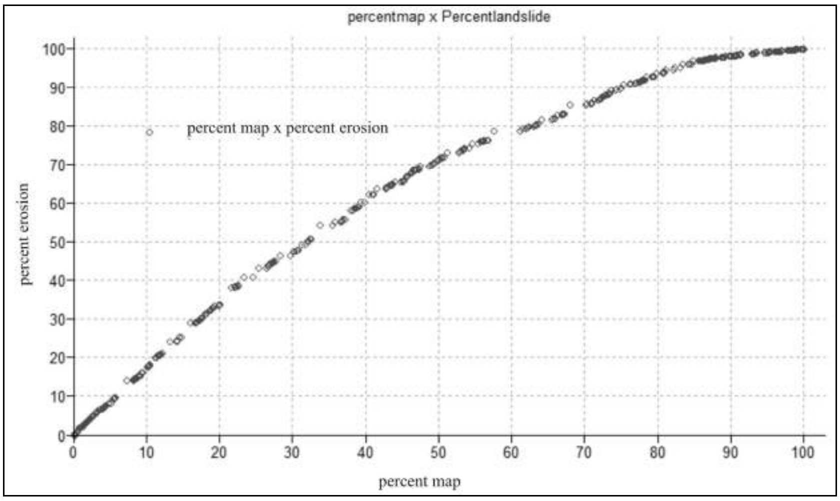


Fig. 15. **Success rate graph**

5. Conclusions

Torrential and other forms of erosion produce soil degradation, land fragmentation and many other damages (destruction of roads, houses, crops cover with materials etc.) for human activities (Ielenicz, 2004). The proposed method is very useful in determining the susceptibility to erosion because it provides quantitative accurate data related to occurrence of slope processes.

This methodology can be applied to any region in order to obtain results for different complex problems. The wide applicability of this method makes it useful both for suitability analysis, impact, and development of areas (mountains, hills, depressions areas) but also to analyze possibility of extending the built area, taking into account all the factors that may be favorable or restrictive.

Such an analysis can capture in the future the environmental influences on human activities and also the human intervention on the dynamic and destabilization of slopes by deforestation, inappropriate use or improper building.

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